Table Tennis Fault Serve Detection

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1. Introduction

1.1 Objective

In table tennis, the service is the most crucial part of every point. It dictates the style and pace of play for the point. In doubles, service becomes even more restrictive where the player can only serve from the right half of his side to the diagonally opposite side of the opponent. Often players try to "jam" the opponent with a serve along the centerline of the table. However, with the speed of the ball and heavy spin generated, it is very difficult for the umpire to determine if a serve was "in" or "out" since he or she is sitting at the side of the table. With organizations like the National Collegiate Table Tennis Association (NCTTA), a doubles match is used as a tiebreaker between two teams who had split results in the singles stage. In such high-stakes matches, even one mistaken call can affect which teams move on in the competition.

Our goal for this semester is to design a table tennis fault serve detector. The detection system must be integrated into the table and must not interfere with gameplay. This means that all equipment must be confined to either the area on the net post or underneath the table. A camera located near the umpire's table will observe the table and determine when a ball is in the field of play using image processing methods on a Raspberry Pi (RPi) microcontroller. Simultaneously, there are two ultrasonic sensors connected to the net posts observing the table. The output from these sensors will be transmitted to the RPi through Bluetooth from the AtMega controller under the table. This data will include the correct call for the play. Once the ball's height reaches a threshold level as determined by the camera/image processing, the RPi will interpret sensor data for that point in time and send the corresponding "in" or "out" signal to the display.

1.2 Background

Currently, there are no devices on the market that detect the validity of the serve for specifically table tennis. However, there are systems, such as Hawk-Eye, used in many sports including tennis and cricket to track the position of the ball. Hawk-Eye technology combines the views from at least six cameras to produce a 3D perspective of the ball's trajectory [1]. Although Hawk-Eye is highly accurate, it would not be practical to implement such a system in table tennis. These systems are very expensive, and at times, there are several table tennis games occurring at once. This would result in the need for many systems. By developing a cost-effective, compact serve detector, implementation of such systems in table tennis would be more feasible.

1.3 High-Level Requirements

- Requirement 1: The device must not be placed anywhere on the table to minimize any hindrance to the game.
- Requirement 2: The system must be able to operate for at least 45 minutes.
- Requirement 3: System must be accurate within 5 mm as the width of the middle white line is 3mm.

2 Design

2.1 Block Diagram

The block diagram for our implementation is shown in Figure 1. The main components of our design include the sensor system, camera system, output display, and power supply. The power to the different components, via a cable, will be supplied from batteries fixed either under the table or alongside the components by the umpire's table. The two sensors will be placed on each side of the table, affixed on a right angled protrusion from the net post. The camera, which is situated by the umpire's table at the same height as the table tennis table, will observe when the ball reaches within height X of the table (X depends on frame rate and worst-case ball vertical velocity). Simultaneously, the outputs of the two ultrasonic sensors will be fed into the ATmega, and transmitted wirelessly to the RPi. The sensor comparison, at this time, will determine if the ball was "in" or "out". The decision is reflected by the LED display.



Figure 1: Block Diagram

2.2 Physical Design

The setup we describe here is for one player's side of the table. A complete system would need a second identical system for complete use in gameplay. As to not hinder either of the players' line of sight, each ultrasonic sensor will be placed on either side of the table and attached to the net post. Attaching to the net post ensures alignment of the sensors because net and net post alignment is already part of table setup for tournaments. This will be done by adding a 1.5" right angle extension to the net post on which the sensor will be mounted. As it can be seen in Figure 2, the sensors will be angled towards the middle of the table. Although the minimum field of view (FOV) of the sensors may not cover the 12 inches of the middle line from the net. This area was intentionally ignored as we showed empirically that serves will not land within one foot of the net. Our experiment for the same is shown in Figure 3. The markers placed on the table signify the location of the bounce of the minimum.



Figure 2: System overview (net [2])

The battery, microcontroller, and Bluetooth transmitter for the sensor system will be fixed below the game table. The display will be placed near the umpire. The display will contain the camera, LED, battery, and RPi. The camera needs to be facing the table and must be placed at a height equal to that of the table so that the X=0 plane of the camera's view coincides with the table. The height of the camera is calculated to be 2.5 feet above the floor which is the vertical height from the ground to the surface of the table. Refer Figure 4 for a detailed view of the camera. The output display LED will be placed behind the camera on the stand along with the battery and RPi.



Figure 3: Experimental serve bounce locations used for determining the minimum required field of view



Figure 4: Camera view (dotted line X indicates threshold)

2.3 Sensor Module

2.3.1 Ultrasonic Sensor

The 2 ultrasonic sensors each have a receiver and transmitter unit which will have a detection range including the center white line. These will be placed along the side of the net post facing the table. The transmitter unit will emit a fixed number of square wave pulses using a LM555 timer circuit described in detail in transmitter section below.

The frequency of these pulses will be 40 KHz which is in the ultrasonic range. The square wave emitted will travel at the speed of sound (343 m/s in dry air) and will bounce off an object in range and reflect back. This reflected signal is picked up by the ultrasonic receiver and the time it takes between transmission and receiving is calculated. Using Eq. (1) where speed (s) = 343m/s, time is t calculated, we can measure the distance of the object. The time will be divided by 2 to account for forward and reverse wave propagation.

$$s = d/t \tag{1}$$

This is the basic principle of ultrasonic ranging. However, our design uses differencing to determine the position of the ball. We are not concerned with the accurate distance to the ball served, rather which sensor it is closer to. Both the sensors will transmit at the same time and are placed on opposite ends of the table. From a high level standpoint, this problem comes down to which sensor received the reflected signal first. If sensor 1 received the reflected pulse first, the ball is closer to that side of the table.

The operation of the transmitter and receiver is controlled by the ATmega Chip as seen in the sensor system block diagram shown in Figure 5. The ATmega controller is connected to the reset pin of the both the transmitter LM555 timers through Hex inverters and also accepts the amplified input from the sensor receivers.





Timing Circuit

The LM555 timer circuit is shown in Figure 6a. It is being used in the astable mode where it as a multivibrator, continuously cycling between a high and low output value[12]. This means that it will continuously transmit a square wave pulse until it is reset. The frequency and time period of the waveform is calculated by the equations below. We chose our R_1 , R_2 , and C to satisfy Eq. (2) to get a 40 kHz square waveform in the ultrasonic frequency range. The frequency of oscillation is determined by the given formula

$$f_c = \frac{1.44}{R_2 + 2R_1} C \tag{2}$$

Based on commonly available capacitor and resistor values, we chose R2=3.8k Ω , R1=8.2k Ω , and C2= 1.8nF.

The simulated operation of the timer circuit using TINA-TI software tool and the corresponding waveform is shown in Figure 8. The initial TINA-TI schematic file [3] was modified with different component values to produce a 40 KHz waveform. The time period of the output square wave pulse is calculated by Eqs. (3-5) where t_h is the time for which the pulse is high and t_l is the time for which the pulse is low. Together, they add up to give the time period of the waveform with a duty cycle of 59.8%.

$$t_h = 0.693(R_2 + R_1)C \tag{3}$$

$$t_l = 0.693(R_2)C \tag{4}$$

$$time \ period = t_h + t_l = 0.0249 \ ms \tag{5}$$

The time period and frequency of operation of the LM555 timer is verified by the simulated output waveform in Figure 6b. Furthermore, we assembled the LM555 timing circuit on a breadboard with the LM555 chip and the required resistor and capacitor values. The output of this lab test is shown on the oscilloscope in Figure 7. The frequency is 40.65 kHz, and the time period is 0.02496ms which is only slightly different than the calculated value. This was expected due to tolerance issues with passive components. This is dealt with in our tolerance analysis section.



Figure 6a: Circuit schematic of TLC 555 timer using TINA-TI schematic file[3]



Figure 6b: Simulation waveform of TLC 555 timer using TINA-TI schematic file[3]



MSO-X 6004A, MY54390377: Thu Mar 09 23:19:16 2017

Figure 7: Tested waveform of assembled LM555 timing circuit

Transmitter Circuit:

The complete transmitter circuit consists of the LM555 timing circuit with a transistor drive circuit for the transmitting sensor as the sensor is a large capacitive load. It also includes the Hex inverter chip connected to the reset pin of the LM555 timer. This inverter is controlled by the ATmega Chip. The circuit schematic and EAGLE board layout are shown in Figures 8 and 9 respectively.

For our design, we want to send only a couple pulses at a time, and then reset the timer for a specified period which is determined in following calculations. This is so that if we do receive a return pulse after a certain time after the transmission, we know that it is due to an object appearing within its range. A continuous transmission waveform would not have been able to accurately characterize the delay.

The timing of the pulses is set by the ATmega chip. Since the astable multivibrator triggers itself and alternates between the two states of high and low[12], thus generating a continuous waveform, we achieve our pulsing mechanism by connecting to the reset pin instead. Pin 4 of the LM555 timer is the reset pin, which is active low. This means that when the input is low, the output of the timer is reset to 0V and does not transmit a pulse. This pin is connected to the ATmega controller through a Hex Inverter. We use a Hex inverter so that we can get true "high" and "low" input to the reset pin. This is to prevent any false reset of the LM555 timer due to any stray voltages.



Figure 8: Ultrasonic transmitter circuit in EAGLE



Figure 9: Ultrasonic transmitter PCB layout in EAGLE

The time in between reset signals is determined by the furthest distance the sensor can "see". For example, if the ball is at the farthest corner of the table from the sensor diagonally 6.7ft away, a wave reflected from that ball will reach the receiver in 11.9 ms at room temperature. We add a buffer of 3 feet to this distance as the player stands within that range and his/her movements could also reflect back to the sensor. Therefore, our total distance of concern is 9.7 feet, and the corresponding time between transmit and receive for that distance is 17.2 ms at room temperature. If our sensing timing is less than that, the sensor could detect delayed excitation at the receiver as a newly transmitted pulse would have been sent in the time that we are still receiving the previous transmission reflection. Therefore, we set our reset time to 17.2 ms.

As calculated before in Equation 5, the time period of one pulse emitted at 40 KHz by the LM555 timer is 24.5 microseconds. For testing purposes, we wanted to send 4 pulses and then reset for 100 microseconds. To send 4 pulses, we set the output of the ATmega controller low for 100 us (roughly 4 pulses). This makes the output of the Hex inverter 1 and the LM555 transmits. Subsequently, we set the output of the ATmega chip as high for 100 microseconds. The output from the Hex inverter is then 0 and this resets the LM555 chip as the reset pin active low.

This LM555 pulsing mechanism is shown in Figure 10. Figure 10 is an oscilloscope reading of the LM555 timer circuit being triggered by the microcontroller. For our lab test, we set transmit time to 100 microseconds and the 4 pulses are visible. However, the pulses do not appear "clean". To resolve this issue, the output from the microcontroller is inverted. This will ensure that all low voltages appear as very close to 0V and all high voltages appear between 4V and 5V. The new waveform can be seen in Figure 11. The reset time for this test was set to 100 microseconds. However, as we calculate in the previous paragraph, the actual reset time is calculated by our max distance of detection which is 9.7 feet from the sensor which will be set to 17.2ms. This is easily altered in code.

From Figure 11 we observe that the width of the first pulse is noticeably larger than the other 3 pulses. This is because the capacitor is initially fully discharged and hence takes longer to charge to 2/3 of the voltage. For the rest of the pulses, the capacitor has discharged to 1/3 of the voltage, so it returns to 2/3 of voltage in less time. [11]



Figure 10: Microcontroller pulsing the LM555 timer



Figure 11: Microcontroller pulsing the LM555 timer after inversion

The output of the LM555 timer is fed into a transistor driver to drive the large capacitive load which is the sensor. From the datasheet [4], C = 2100 pF and max voltage in R_{ms} for the sensor is 30 V_{rms} . Plugging into Eqs. (6-7) where f = 40 kHz, the max input current to the sensor is found.

$$X_c = \frac{1}{\omega C} = \frac{1}{2\pi f C} \tag{6}$$

$$I_{rms} = \frac{V_{rms}}{X_c} = 15.833 \ mA \tag{7}$$

The transistor used in the NPN 2N2222A. If the transistor is in saturation, there is very little resistance across the emitter and collector. R_L and R_B calculations for the transistor is given by Eqs. (9-10). From the datasheet for the 2N2222A [5], for i =10mA and V_{ce} =10 V_{dc} , the gain (hfE) is equal to 35.

$$V_{RL} = 5V (source power) \tag{8}$$

$$R_L = 568.42 \,\Omega \tag{9}$$

$$R_B = 0.2 * R_L * hFE = 3.979 \, k\Omega \tag{10}$$

Receiver Circuit and Distance Determination:

The receiver circuit consists of the receiver sensor and an operational amplifier. The operational amplifier is set up with feedback resistors to achieve a specified gain. The gain will be determined by observing the strength of the received signal from the ultrasonic sensor and comparing it to the op-amp's saturation voltage (5V).

To implement the amplifier with the op-amp, we needed to compute the resistor values for R_1 and R_2 . For the amplifier design, it is known that the gain G can be computed as shown in Equation 11. We find the ratio of R_2 to R_1 by rearranging this into the form shown in Equation 12. For example, if we need a gain of 100, the ratio will be calculated as shown in Equation 13. This circuit layout is and Eagle Board is shown in Figure 12 and 13 respectively. The resistor values are specified for a gain of 100 and can be easily changed for a different gain if needed.

$$G = 1 + \frac{R_2}{R_1} \tag{11}$$

$$\frac{R_2}{R_1} = G - 1 \tag{12}$$

$$\frac{R_2}{R_1} = 100 - 1 = 99 \tag{13}$$



Figure 12: Ultrasonic Receiver Unit Circuit Schematic for Example Gain 100



Figure 13: Ultrasonic Receiver Unit Eagle Board Layout for Example Gain 100

Beam Angle Calculation

Figure 14 shows the how the minimum sensor view angles were calculated. Using Eqs. (14-16), the beam angle required was calculated to be 37.875° total. Our choice of sensor has a beam angle of 70° , thus covering a wider area.

$$\theta_1 = \tan^{-1}\left(\frac{1ft}{3ft}\right) = 18.435^{\circ} \tag{14}$$

$$\theta_2 = \tan^{-1}\left(\frac{4.5ft}{3ft}\right) = 56.310^{\circ} \tag{15}$$

$$\theta_{view} = \theta_2 - \theta_1 = 37.875^\circ \tag{16}$$



Figure 14: Sensor FOV

2.3.3 ATMega Microcontroller

The ATmega328p was chosen as the microcontroller for the sensing module because of its simple user interface. The microcontroller will receive an analog input from each sensor and transmit the appropriate signal to the Bluetooth module for communication. It will also provide the reset signal for the LM555 timer.

2.3.3 Bluetooth Transmitter

The Bluetooth module (HC-05) will be connected directly to the ATmega328. Once it receives a signal from the microcontroller, the signal will then be transmitted to the Bluetooth receiver in the RPi.

2.4 Camera Module

2.4.1 Camera

We purchased the Raspberry PI 5MP Camera Board Module as our camera. The listed 5 MP is the maximum resolution for static images. For video, the camera can take video with 640x480 pixels at either a frame rate of 60 or 90 fps.

The camera will be situated near the umpire's table at the same height as the playing table. This will allow the camera to observe the ball as it approaches the table, bounces, and leaves the table. The choice of frame rate is dependent on what the RPi can handle. Related calculations are shown in the RPi Microcontroller section.

2.4.2 RPi Microcontroller

The RPi will have two inputs: the images captured by the camera and the output from the ultrasonic sensors. The microcontroller performs blob detection to determine the location of the ball, perspective calculations to determine when the ball is hitting or about to hit the table, and then uses the sensor measurement input to relay whether or not the ball was "in" to the display. We can compute the height of the ball off the table based on the position and size of the ball in the image.

In the camera section, we described our video options of 60 or 90 fps at 640x480 pixels. Below we compute the minimum necessary memory and clock speed to be able to provide the real-time analysis we are targeting for each of these frame rates. This can then be compared to the specifications of the RPi to determine if the frame rate will be compatible with the RPi's processing speed. We use 5 floating point operations per channel as a standard factor for algorithms of similar complexity. In the calculations below, let: M = necessary amount of memory, c = number of channels, p = number of pixels, f = clock frequency, r = frame rate, and x = computation complexity.

$$M = c * p \tag{17}$$

$$M = 3 * (640 * 480) = 921,600Bytes$$
(18)

$$f = r * c * p * x \tag{19}$$

$$f = 60 * 3 * (640 * 480) * 5 = 524.16 [MHz]$$
⁽²⁰⁾

$$f = 90 * 3 * (640 * 480) * 5 = 786.24 [MHz]$$
⁽²¹⁾

From the datasheet for the RPi 3 Model B, the clock speed of the microcontroller is 1.2 GHz [10] showing that the computational capabilities of the RPi will be sufficient to perform the image processing in real time for either frame rate video.

The image processing will be performed in software within the RPi microcontroller. The software must be able to first locate the ball, if visible, and distinguish the table from the rest of the scene. Once the ball reaches a threshold height above the table, the RPi microcontroller will read the input from the corresponding transmitted signal (via Bluetooth) and send a signal to the display. There is a built-in Bluetooth module with the RPi 3 Model B. There will be some constant delay between the microcontroller's detection of the ball and when the sensor results are received by the microcontroller. The full software logic is described in Figure 15.



Figure 15: Software flowchart

2.5 Output Display

2.5.1 Display LEDs

The display will consist of a single LED that can emit both red and green. This LED will be connected directly to and powered by the RPi. Once a signal is received, the LED will light up green ("in") or red ("out") depending on the location the ball bounces. The umpire will have the ability to manually reset the LED after each play to prevent any confusion between serves.

2.6 Power Supply

2.6.1 Battery

The power source for the detection system consists of one 9V (500mAh) battery and a 5V/2A (5200 mAh) lithium-ion rechargeable battery power pack. The 9V battery will power the ATmega328 microcontroller located at the table tennis table and the two ultrasonic comparators. This battery will last for approximately 7 hours. The rechargeable battery will be used to power the RPi as well as the camera and LED attached to the RPi. It will provide enough power for approximately 2 hours.

2.6.2 Power Converter

Voltage for the ATmega328p and sensor circuit will need to be stepped down. The sensor circuit can operate at 5V and the ATmega328 chip is operable at a voltage between 1.8V and 5.5V. Thus, a buck converter (LPS54202DDCT) is chosen to step down the voltage from 9V to 5V. It should allow no more than a ±5% output voltage ripple. By choosing 5%, voltage requirements for the microcontroller and circuit will still be within the operational range. The minimum output current should be 70 mA. Figures 16 and 17 display the buck converter design as well as input and output voltage simulations using TI Tina Simulator [13]. Since the rechargeable battery pack has an internal regulator, an external one will not be necessary. The battery should be able to provide the necessary 5V/2A to the RPi. The EAGLE schematic for the converter is seen in Figure 18.

Figure 16: 9V to 5V buck converter schematic

Figure 17: 9V to 5V buck voltage simulation

Figure 18: EAGLE schematic for the buck converters

2.7 Tolerance Analysis

In our design, we require a power converter. The stepped down voltage, its ripple, and current are considerations that must be kept in mind when designing the power supply. In Table 1, the component operating voltage and currents are listed for those connected to the buck converter. Noting that chosen voltages and current are within range, it is important that the voltage ripple is not too large. For our power supply requirement, we proposed a $\pm 5\%$ voltage ripple maximum value.

Component	Voltage Rating	Voltage Chosen	Current Rating	Current Chosen
Ultrasonic sensor 1	30 V	5 V	-	~30 mA
Ultrasonic sensor 2	30 V	5 V	-	~30 mA
ATmega328	1.8 V - 5.5 V	5 V	9.5 mA	4.1 mA

Table 1: Component voltage and current values

By adhering to this requirement, there should not be trouble with operating any of the components. If voltage is not within ±5% of the desired voltage, and current falls below the proposed minimum of 70 mA, problems may arise. A ripple of over 5% puts the ATmega328 beyond its operating voltage. This may be troublesome resulting in safety concerns specified in Section 4, especially if not taken care of immediately. In the TPS54202 datasheet [6], approximated output voltage ripples can be found for different loads. For both 10mA and 100mA, the output ripple is 20mV/div. Even though this is well under our ±5% range, it is still important considering our circuit may not be as ideal as their test circuit.

Since we are building our own sensor circuit module, each passive component will add a certain degree of tolerance. For the transmitter circuit, the values of the resistors and capacitors will change the output frequency. However, with a 10% tolerance of R_1 , R_2 and C, the frequency will fluctuate from 33.97 KHz to 49.38 KHz. This isn't an issue as these frequencies are still in the ultrasonic range and will travel at the speed of sound.

To determine the delay from the microcontroller in which the square wave signal transmits, the speed of sound at varying temperatures needs to be considered. Using Eq. (22), the speed of sound (v) at different temperatures (T) can be found [7]. Based on a room temperature of 23°C, the speed of sound is 345 m/s. Given that the temperature of a tournament room would likely rise to no more than 30°C, the speed of sound would increase to roughly 349 m/s. Higher temperatures cause a decrease in the time delay which does not negatively affect our design. Also, a change in temperature will affect both sensors equally and since we are taking a difference measurement of the two, it will not affect our measurements.

$$V[m/s] = 331[m/s] + 0.6[m/(sC)] * T[C]$$
(22)

Additionally, we need to consider the uncertainty in the position of the ball from the camera. The position of the ball is critical to determining which sensor measurement contains the result of the comparison at the time of contact. There are two sources of this timing uncertainty: frame rate and motion blur.

The camera we are using as a frame rate of 90 fps [10]. This means that there will be one image available to analyze every 11.11 milliseconds. In between those 11.11 milliseconds, we do not have any information on the location of the ball. Since it is unlikely that the ball will bounce exactly at the time we capture an image, we will have to determine which image contains the ball at the closest time to the time the ball contacts the table.

The image of the ball will also include motion blur. Motion blur is when objects in images appear to have a tail or streak behind it due to the object moving within the exposure time. This tail will be included in the "blob detection" component of the computer vision and will affect the ability of the software to determine the true location of the ball and the size of the ball in the frame.

Requirement	Verification	Points
	Sensor Module	
Ultrasonic Sensor		
<i>LM555 astable multivibrator circuit should emit a frequency of 40 kHz ±10%.</i>	 Connect microcontroller to LM555 to enable reset pin to high (reset is active low). This will generate a continuous square wave. Connect output to oscilloscope. Verify frequency is within 40 kHz ±10%. 	2
Both sensors must be able to view the 3.5 feet of the middle line from the end of the table closest to the player.	 Set ultrasonic sensors in place for design specifications. Connect sensors to oscilloscope. Serve ball along middle line approximately 1 ft from the net. Verify sensors receive signal on oscilloscope. Repeat step 4 for serves approximately 2 ft, 2.5 ft, 3 ft, 3.5 ft, 4ft, and 4.5 ft from net. 	7
Ultrasonic receiving sensors must detect reflected wave at a time delay corresponding to the distance of the ball from the sensor.	 Set ultrasonic sensors in place for design specifications. Connect receiver sensor output to Arduino (for time measurement). Drop ball a specified distance away from sensor. 	5

2.8 Requirements and Verification

		1
	4. Verify distance using microcontroller by measuring time delay in received pulse.	
ATmega Microcontroller		
Must repeatedly send a low signal for 100 us and a high signal for 17.2 ms	 Connect microcontroller output pin to oscilloscope. Run reset signal code which should send a low signal for 100 us and a high signal for 17.2 ms. Verify signal is low for 100 μs and high for 17.2 ms. 	1
Must be able to determine which receiver acquired the reflected signal first.	 Start pulsing the LM555 timers using the ATmega microcontroller Bounce ball close to sensor 1 Observe that ATmega interprets received 4 consecutive pulses in order to return that the ball is closer to sensor 1 Bounce ball close to sensor 2 Observe that ATmega interprets received 4 consecutive pulses in order to return that the ball close to sensor 2 	7
Bluetooth Transmitter		
Must be able to correctly send information with 99% accuracy from sensor to a bluetooth receiving device 12 ft away.	 Program bluetooth transmitter to send a loop of bits of data representing which sensor detected object first. Pair bluetooth transmitter with a bluetooth receiver 12 ft away. Verify correct information is sent. 	3
	Camera Module	
Raspberry Pi		
Must be able to receive 640x480p images at 90 fps from the camera module.	 Read input image from camera. Store in local memory and increment a frame counter Output to computer Repeat for 1 second Observe continuous images on computer Verify that frame counter reaches 90. 	3
Must be able to send a correct signal to the display to cause LED to light green for "in" and red for "out".	1. Hard code a signal to transmit to the display. 2. Observe if the correct LED is green for "in" and red for "out".	1

Must distinguish the table tennis ball from the non-white background and table.	 Return the location of the bottom-most pixel of the ball Return dimensions of the ball (total number of pixels) Display the image on the screen. Compare returned values with raw image 	7
Must distinguish the level of the top of the table tennis table with 90% accuracy.	 Draw a line at the level of the top of the table tennis table on top of the image. Display the image to the screen. Compare returned values with raw image 	5
	Output Display	
The display must clearly show if ball is "in" or "out" for the play.	1. Hard-wire input from the ARM microcontroller. 2. Check if LED displays green for "in" and red for "out".	1
The display must be reset after each play.	 Trigger LED. Press button to manually reset LED. Check if LED is off. 	2
	Power Supply	-
Battery		
The 9V battery must be able to feed the buck converter a minimum of 5V for at least 45 minutes.	 Connect battery to buck converter and multimeter. Measure voltage every 5 minutes. Verify the voltage never falls below 5V. 	3
Buck Converter		
Buck converter must output a voltage of 5V with a ±5% voltage ripple and a minimum current of 70mA	 Connect resistive load to buck converter. Supply converter with 9V. Connect output to multimeter. Verify voltage is 5V with a ±5% and current is a minimum of 70mA. 	3
	Total Points	50

3 Cost and Schedule

3.1 Cost Analysis

PARTS					
Description	Manufacturer	Part #	Quantity	Unit Cost	Total Cost
		Sensor Module			
555 Timer	Texas Instruments	TLC555 Timer	2	\$0.95	\$1.90
Ultrasonic Receiver 40 KHz	PUI Audio, Inc	UR-1240K-TT-R	2	\$4.95	\$9.90
Ultrasonic Transmitter 40 KHz	PUI Audio, Inc	UT-1240K-TT-R	2	\$4.95	\$9.90
Hex Inverter Chip	Texas Instruments	SN7404	2	\$2.02	\$4.04
Ultrasonic Tx PCB	PCBWay	N/A	5	N/A	\$10
Ultrasonic Rx PCB	PCBWay	N/A	5	N/A	\$10
Bluetooth Transmitter	JBTek	НС-05	1	\$5.41	\$5.41
ATmega328	N/A	N/A	1	\$25.00	\$25.00
Passive Elements	N/A	N/A	N/A	\$5.00	\$5.00
		Tota	al for Senso	or Module	\$71.15
Power Supply					
9V Alkaline Battery	Panasonic	6LF22XWA/1SB	1	\$1.68	\$1.69
Buck Converter IC	TI	TPS54202DDCT	1	\$2.04	\$2.04
Rechargeable Battery	Anker	Astro E1	1	\$15.00	\$15.00

Passive Elements	N/A	N/A	N/A	\$5.00	\$5.00
		Tot	tal for Pow	er Supply	\$23.73
		Camera Module			
RPi microcontroller	Adafruit	Pi 3 B	1	\$39.95	\$39.95
CMOS Camera	RPi	5 MP Camera Board Module	1	\$21.99	\$21.99
Total for Camera Module					\$61.94
		Output Display			
	C LED		4	¢1.00	¢1.00
LEDS	SunLED	8	1	\$1.02	\$1.02
Passive Elements	N/A	N/A	1	\$5.00	\$5.00
Total for Output Display				\$6.02	
				#4 (D O 4	
TOTAL PARTS COST				\$162.84	

LABOR				
Name	Hourly Rate	Hours	Total	Total x 2.5
Shraddha	30	250	\$7,500	\$18,750
Vishesh	30	250	\$7,500	\$18,750
Katelyn	30	250	\$7,500	\$18,750
TOTAL LABOR COST \$56,250				
TOTAL COST				\$56,412.84

3.2 Schedule

Week	Shraddha	Vishesh	Katelyn
2/27	-Buy components for ultrasonic transmitter and receiver circuit and start building the circuit on breadboard	-Choose an ARM processor and camera specifications based on processing power -Decide on FastCV vs OpenCV or other image processing/computer vision software	- Finalize design for power supply depending on processor choice -Buy components for power supply circuit
3/06	-Simulate output frequency from LM555 timer on oscilloscope -Control LM555 through ATmega controller	-Design PCBs for ultrasonic sensors -Build PCB for ATmega microcontroller	-Build and test power supply on breadboard
3/13	 Provide 40 KHz input to receiver circuit and measure output voltage of receiver circuit Determine range of sensor Test ultrasonic transmitter and receiver as a unit and check accuracy of distance measurement Make any modifications necessary and send final PCB layout to the ECE shop 	-Blob detection in software (i.e. be able to locate ball and table in a static image) -Design PCB for display	-Finalize and purchase buck converter PCBs -Build and test output display circuit
3/20	-Work with ECE Machine Shop to build a mock table and a mount to place the final sensors on -Test both transmitters and receivers together with the controller and verify that it correctly evaluates which sensor the ball is closer too	-Determining height of the ball in software -Begin integration of full algorithm	-Solder components on PCB -Record voltage measurements and ripple -Verify battery powers supply for 45 minutes.
3/27	-Connect to microcontroller bluetooth module -Finalize microcontroller code	-Integration of full algorithm -Software debugging for static images	-Test wireless display PCB -Start on Bluetooth code

4/03	-Verify that transmitted data from microcontroller and received data at the Pi are the same	<i>-Work out timing delays between sensor and camera</i>	-Characterize measured Bluetooth time delay into final code
4/10	-Final hardware testing	-Final testing of software	-Hardware/software integration
4/17	-Mock Demo -Ensure sensor requirements are met	-Mock Demo -Ensure camera module requirements are met	-Mock Demo -Ensure power supply and bluetooth requirements are met
4/24	-Add in test results of sensor module and microcontroller to final report -Demonstration	- Add in test results of camera module and Rpi to final report -Demonstration	- Add in test results of Bluetooth module and power supply to final report -Demonstration
4/31	-Final Report -Submit Final Report	-Final Report -Lab Checkout	-Final Report -Format Final Report

4 Safety and Ethics

It is important that our fault serve detection system complies with the IEEE Code of Ethics not only during the developmental stage but as well as after the design is implemented. There are a couple safety concerns that need to be taken into consideration in order to abide by IEEE Code of Ethics, #1 - "to accept responsibility in making decisions consistent with the safety, health, and welfare of the public..." [9]. If voltage or current limits are exceeded for any of the components, such as the passive elements as well as the microcontrollers, there is a possibility of the particular component overheating and/or combusting. If such an occurrence were to happen, the equipment, particularly the net and table, could be damaged. It also poses a risk to anyone near the system at the moment including the players, the umpire, and/or any audience members nearby. To combat this issue, correct calculations for the power supply are essential as well as thorough testing of the system.

There is also potential safety concerns with the use of the lithium-ion rechargeable battery including both chemical and electrical hazards. Lithium-ion batteries consist of lithium for the anode as well as a material for the cathode which is usually nickel or manganese and cobalt [8]. Although the battery should not release any chemicals, there is the potential risk of leakage. This could be due to corrosion or damage to the battery. Another potential risk for the lithium-ion battery is the possibility of overheating and/or combusting. This could occur if the battery is charged and discharged too quickly. The excess charging increases internal temperature and could also result in chemical unpredictability. A third issue could result if the components are not securely fastened. Any loose components could act as projectiles if hit correctly. As a result, all parts of the system will be able to be thoroughly secured.

To comply with IEEE Code of Ethics, #3 - "to be honest and realistic in stating claims or estimates based on available data" [9], it must be reiterated that our system will likely not be 100% accurate. The system should not be altered in any way as any changes could affect the accuracy if not recalibrated.

The intended use of our design is for indoor table tennis games. Using the system in an outdoor environment poses the risk of damaging components in the presence of hazardous weather conditions.

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